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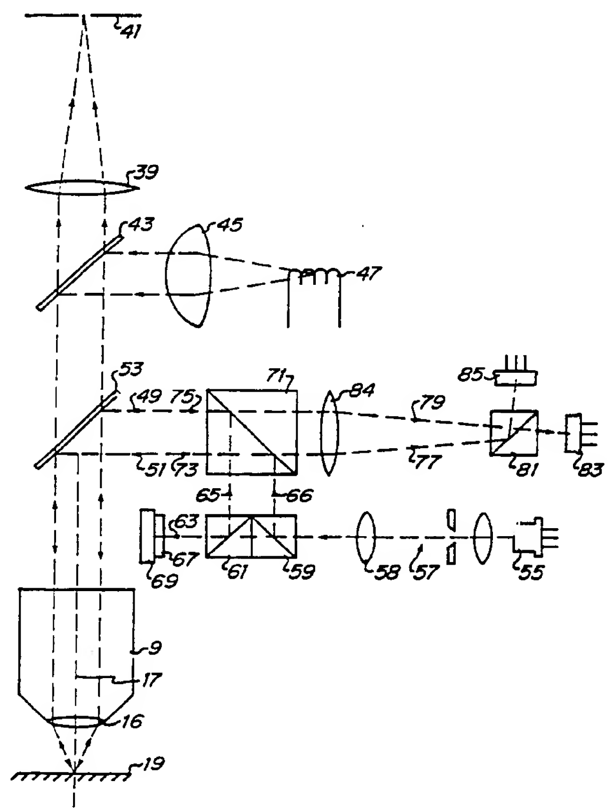
(54) Title: LASER AUTOFOCUS APPARATUS AND METHOD

(57) Abstract

An auto-focus system and method for an optical imaging system introduces a pair of spaced laser beams (11 and 13) into the imaging system (9) to illuminate a work surface at slight converging and symmetrical angles. The reflections (23, 25) of the beams from the work surface are translated by the imaging system (9) to detectors (29 and 31) at an image plane which produce detector output signals that are processed to produce a focus-adjusting control signal. Laser power is also corrected in accordance with levels of detected reflections to provide wide dynnamic range of surface reflectance conditions.



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LASER AUTO FOCUS APPARATUS AND METHOD

Field of the Invention

This invention relates to auto-focusing systems, and more particularly to a structure and method for focusing an optical imaging system using laser beams directed through the optical imaging system.

Background of the Invention

Focusing schemes for optical imaging systems should be non-contacting and operate through the lenses of the optical imaging system to assure continuous and repeatable operation within the environment of the optical imaging system. In addition, such auto-focusing schemes should be relatively insensitive to the tilt angle and reflectivity of the surface being viewed through the optical imaging system. Also, it is highly desirable for an auto-focusing scheme to have a wide capture range and be able to follow variations in elevation of the surface during scanning motion of the optical imaging system over the surface.

Summary of the Invention

Accordingly, in the present invention two laser beams are introduced off axis into an optical imaging system to form a symmetrical pair of beams that emerge from the imaging system to illuminate a work surface at a slight angle. The reflection from each spot of illumination on the work surface propagates back through the optical imaging system to at least one detector at an image plane, and such reflection thus moves across the detector, with the space between the reflections increasing more or less linearly with the distance separating the work surface and the focal plane of the optical system. The symmetrical pair of beams and the associated reflections thereof from a work surface are processed to eliminate effects of such conditions as tilt in the work surface on the location of the reflected spots on the associated detectors. Higher

magnification in optical imaging systems provides higher leverage between movement of illuminated spots on a work surface with changes in focal distance and the movement of the reflected spots on the detectors at the image plane. By isolating each beam, for example, by polarizers or different wave lengths or time-shared operation, then position-sensing detectors can be used on each channel of illuminating and reflected beams, and the difference in detected signal levels divided by the sum of detected signal levels yields a compensated real-time output representative of focal distance between a work surface and the optical imaging system.

Description of the Drawings

Figure 1 is a pictorial diagram of an optical imaging system equipped with a pair of focus-sensing beams according to the present invention;

Figure 2 is a chart illustrating the intensity as a function of radius of the reflected spot;

Figure 3 is a pictorial diagram of a reflected spot upon a two element position-sensing detector of Figure 1;

Figure 4 is a pictorial diagram of a preferred embodiment of the present invention;

Figures 5, 6 and 7 are pictorial diagrams illustrating the optical conditions around focal distance to a flat work surface;

Figures 8, 9 and 10 are pictorial diagrams illustrating the optical conditions around focal distance to a tilted work surface;

Figure 11 is a pictorial diagram illustrating the optical conditions near an edge of a work surface;

Figure 12 is a pictorial diagram illustrating the optical conditions about the focal distance to a rough work surface;

Figure 13 is a block schematic diagram of a control circuit according to the present invention;

Figure 14 is a graph illustrating error signal response to lateral movement of a reflected spot on the detector in accordance with the present invention;

Figure 15 is a chart illustrating control of laser power according to the present invention; and

Figure 16 is a flow chart illustrating the operation of this present invention.

Description of the Preferred Embodiment

Referring now to the pictorial diagram of Figure 1, there is shown a simplified embodiment of the present invention for operation in an optical imaging system such as a microscope, or the like. A pair of laser beams 11 and 13 having different optical polarities are introduced into the imaging system 9 through beam splitter 15, to establish a pair of beams substantially symmetrically off-axis about an axis of optical symmetry 17 of the imaging system 9. Due to the off-axis orientation of the two incident beams 12, 14, these beams pass through the objective lens 16 of the imaging system 9 at a slight converging angle toward the focal plane 19. At focus, such incident dual beams 12, 14 produce co-located spots of illumination 21, 22 on a work surface located in the focal plane 19. The reflections 23, 25 from such surface of the incident-illuminated spots 21, 22 pass back through the objective lens 16 and the associated imaging system 9 and are partially reflected by beam splitter 15 to the beam separator 27. There, the reflected, split beams from the illuminated spots 21, 22 are separated and directed to detectors 29 and 31 which lie substantially in the image plane of the optical imaging system 9. Therefore, at focus, the reflections from the illuminated spots 21, 22 are re-imaged as spots on the respective detectors 29, 31 with an intensity profile substantially as illustrated in the graph of Figure 2. More importantly, however, as the distance between a work surface and the objective lens of the imaging system 9 varies about the focal distance, then the illuminated spots 21, 22 will part and move away from each other on such surface, and correspondingly the reflected spots will move on the detectors 29, 31 at the image plane in direct or linear relationship to the spacing of a reflecting surface about the focal plane 19, as illustrated in Figure 3. The detectors 29, 31 may each include active optical sensing segments 33, 35 disposed about a gap 37 to

produce output signals in conventional manner that correspond to the level or intensity of the reflected radiation 23, 25 that is incident upon the active segments 33, 35. Referring also to Fig. 14, the difference of output signals from the segments 33, 35 for each detector 29, 31 will be zero when reflections 23, 25 are coincident or when they lie outside the active segment areas 33, 35. As the reflections 23, 25 move from the outer edges of the active segments 33, 35, the detector difference signal changes from a maximum level 134 to zero 135 through curve slope 133. This output signal information from a pair of detector segments for each reflected spot operates control circuitry for automatically adjusting focus conditions in the manner as later described herein.

Referring now to Figure 4, there is shown a pictorial diagram of the preferred embodiment of the present invention for operation with the optical imaging system 9 having at least an objective lens 16. The imaging system may also include an image-forming lens 39 for forming on an image plane 41 a real image of an object on the focal plane 19. Optionally, an optical port including a beam splitter 43 and lens 45 may be included in the imaging system to facilitate the illumination of a sample below the objective lens 16 using a light source 47.

In accordance with the present invention, a pair of laser beams 49, 51 are introduced into the imaging system 9 via a dichroic-mirror type of beam splitter 53 which passes visible-band light (substantially in the vertical direction in the illustration) and which reflects infra-red radiation (substantially along the horizontal direction in the illustration). Thus, eyeball or camera viewing at the image plane 41 is uninterrupted by infra-red auto-focusing operation according to the present invention.

Specifically, laser diode 55 produces a beam that may be collimated and adjusted in diameter in conventional manner 57 to supply a beam of horizontally-polarized infra-red radiation to a partially-transmissive beam splitter 59. A portion of the infra-red beam that is incident upon the non-polarizing beam splitter 59 is applied to a conventional polarizing beam splitter 61 which passes a portion 63 of the

horizontally-polarized beam (horizontally, as illustrated). The horizontally-polarized beam 63 passes through a quarter-wave plate 67 (at the wavelength of the laser beam) which produces circular polarization of the beam passing therethrough to the reflective mirror 69. Therefore, the reflected, circularly-polarized portion of the laser beam returns through the quarter-wave plate 67 and reflects vertically 65 from the polarizing beam splitter 61. Also, moving the assembly of beam splitters 59, 61 laterally relative to the laser beam 57, alters the spacing between the resultant incident beams 65 and 66. Of course, separate beams may also be selectively segregated using separate laser diodes that emit, for example, at different wavelengths, or in time-shared relationship.

The vertically - and horizontally - polarized beams 65, 66 are supplied to the beam splitter 71 to provide incident beams 49 and 51 previously described. In addition, the beam splitter also receives the separately-polarized beams of reflected radiation 73, 75 from the optical imaging system and produces therefrom the vertically-polarized 77 and the horizontally-polarized 79 resultant beams which are applied to the polarizing beam splitter 81. An image-forming lens 84 may be included in the paths of the resultant beams 77, 79 to image the respective reflected polarized beams thru the polarizing beam splitter 81 and onto the associated detectors 83, 85. Thus, detector 83 only receives vertically-polarized reflected beam 77 and detector 85 only receives horizontally- polarized reflected beam 79. Since these detectors 83, 85 are positioned at the image plane of the optical system 9, then changes in the focal distance along optical axis 17 between the objective lens 16 of the imaging system 9 and a work surface near the focal plane 19 causes reflected spots to move on the detectors 83, 85 lying in the real image plane, as previously described.

Therefore, with reference to Figures 5, 6 and 7 the pictorial diagrams illustrate the optical conditions associated with a pair of off-axis beams introduced into the imaging system 9, as previously described, to illuminate a work surface 90 at or near the focal plane 19. As illustrated in Figure 5,

the incident beams 91, 93 illuminate spots on the work surface 90 at the focal plane which are exactly coincident or co-located on the focal plane. Reflected radiation 95, 97 from the respective spots passes through the imaging system to form reflected spots 92, 94 that are similarly located at equivalent co-locations on respective separate detectors 83, 85 which lie in the image plane 99, for reasons as previously described. Thus, at focus, the difference of detector outputs (e.g., Left-Right) is zero (or, null). However, as illustrated in Figure 6, a work surface 90 positioned above the focal plane 19 of the imaging system 9 produces separated spots 101, 103 of illumination on the surface 90, with the right beam 93 illuminating the right-side spot 101, and with the left beam 91 illuminating the left-side spot 103. The reflections of these spatially-separated spots 101, 103 are then translated via the imaging system 9 to the image plane 99 onto the detectors where the reflected images 92, 94 of such spots 103, 101 appear as spaced away from the optical axis 17 of the system. Thus, for a work surface 90 disposed above the focal plane 19, the difference of detector outputs (i.e., Left-Right) is greater than zero.

Similarly, with reference to the pictorial diagram of Figure 7, a work surface 90 positioned below the focal plane 19 of the imaging system 9 produces separated spots 101, 103 of illumination on the work surface 90, with the right beam 93 illuminating the left-side spot 101, and with the left beam 91 illuminating the right-side spot 103. The reflections of these spatially-separated spots 101, 103 are then translated via the imaging system 9 to the real image plane 99 onto the detectors where the reflected images 92, 94 of such illuminated spots 91, 93 are spaced away from the optical axis 17 of the system. Thus, for a work surface 90 disposed below the focal plane 19, the difference of detector outputs (i.e., Left-Right) is less than zero.

In accordance with the present invention, the symmetrically-positioned, off-axis pair of laser beams that are introduced into the optical imaging system provide detector outputs, in the manner previously described, that are

substantially immune from tilting of a work surface relative to the focal plane. Specifically, as illustrated in the pictorial diagrams of Figures 8, 9 and 10 for work surfaces 90 positioned, respectively, at and above and below the focal plane 19, the resultant reflected spots 92, 94 from the illuminated spots 101, 103 on the work surface 90 still provide comparable differences of detector outputs (i.e., Left-Right) that are, respectively, zero (null), greater than zero, and less than zero. This is because the reflections from the illuminated spots 101, 103 are translated via the imaging system 9 to the image plane 99 of the detectors with asymmetrical displacement from the optical axis 17 for work surfaces 90 disposed above or below the focal plane 19, and the difference of detector outputs (i.e., Left-Right) remains zero, greater than zero, and less than zero under the indicated conditions of a work surface 90 for Figures 8, 9 and 10 respectively.

In accordance with the present invention, the auto-focusing scheme operates at an edge 102 of a work surface 90 to focus on the proximate surface, as illustrated in the pictorial diagram of Figure 11. Specifically, reflections from the portions of the illuminated spots 101, 103 that are on the work surface 90 are translated via the imaging system 9 to the image plane 99 to form partial reflected images 92, 94 that are asymmetrical (as are the illuminated spots 101, 103 overlaying the edge 102). Thus, the centroid of the area of the images 92, 94 are shifted slightly from the optical axis 17, but the difference of detector outputs (i.e., Left-Right) is nevertheless zero. This condition continues (with movement of the edge 102 of the work surface relative to optical axis 17) until reflections from illuminated spots 101′ and 103′ can be translated back from the lower level of the work surface 90′ disposed below the focal plane 19 in the manner as previously illustrated and described with reference to Figure 7 or Figure 10.

Referring now to Figure 12, there is shown a pictorial diagram illustrating operation of the present invention on a work surface 90 that is rough, irregular or otherwise

defective. Specifically, the left and right beams 91, 93 illuminate spots 101, 103 on the work surface 90, and reflections from the spots are translated via the imaging system 9 to the image plane 99 of the detectors. The reflected images 92, 94 of the spots 101, 103 contain irregular contours attributable to the irregular reflective surfaces within the areas of the illuminated spots 101, 103. However, the effects of the surface on the centroids of area of both reflected spots 92, 94 remain substantially the same; and the difference of detector outputs (i.e., Left-Right) remains zero. Similarly, an irregular or otherwise defective work surface 90 that is tilted relative to the focal plane 19 yields irregular reflected images 92, 94 of the illuminated spots 101, 103, and the centroids of the areas of such reflected irregular spots will be positioned along the image plane 99 of the detectors as previously described, for example, with reference to Figures 8, 9, or 10.

Referring now to Figure 13, there is shown a schematic diagram of the control circuitry according to the present invention for logically converting detector outputs to requisite signals for controlling a focusing motor and the output intensity of the laser light source. The detectors (for example, 29, 31 of Figure 1, or 83, 85 of Figure 4) each include a pair of active segments separated by a gap, as previously illustrated and described with reference to Figure 3. The output signals 111-114 from each of the active segments in the two detectors are added in summing amplifiers 117, 119 to provide sum signals 115, 116 per detector. In addition, the differences 121, 123 between output signals from the segments of each detector are produced by difference amplifiers 125 and 127. These sum and difference signals 115, 116, 121, 123 are used to control the motor 129 which is coupled to a focus adjustment of the imaging system 9, and to control the power output of the laser diode 55 that provides the pair of light beams 23, 25 in Figure 1 (or 65, 66 in Figure 4).

Specifically, with reference to the graph of Figure 14, there is shown the sum 131 and difference 133 signal levels associated with the responses of the pair of segments of each

detector. Thus, as a reflected spot traverses the surface of a detector (lying in the image plane 99) due to movement of a reflective work surface above and below the focal plane, the difference signal 133 is indicated to undergo a transition from zero to a maximum positive value, through zero crossing 135, to a maximum negative value, and to zero. However, the sum signal 131 increases from zero to a maximum-positive value, and decreases to zero. Therefore, critical control of motor 129 is necessary only within a narrow range of difference-signal values about zero crossing 135 that corresponds to the centroid of the reflected spot being positioned substantially at the gap 37 between active segments of a detector (that, in turn, corresponds to focus at the focal plane). Accordingly, the difference signals 121, 123 are amplified in differential amplifier 137 for summation with a user-settable offset signal 139 (later described herein) in amplifier 141 to produce an error signal 143 of requisite amplitude and polarity to drive motor 129 in the corrective direction to achieve focus of the imaging system 9.

At the same time, the sum signals 115, 116 are applied to comparators 143, 145 for comparison with a signal 147 representing the minimum sum level, as indicated in the graph of Figure 14. The comparators 143, 145 thus produce outputs 149, 151 when the respective sum signals exceed the minimum sum level, and the output 155 of AND gate 153 that is connected to receive both outputs 149, 151 thus indicates when both sum signals 115, 116 exceed the minimum sum level. This output 155 thus provides indication of IN-RANGE operation when sufficient reflected light is detected by the detectors to provide reliable focusing operation. This IN-RANGE signal is applied through an inverter 157 to produce an output 159 when the combined sum signals are not IN-RANGE (i.e., insufficient light is detected by the detectors to permit reliable focusing operation. While light conditions are suitable for reliable focusing operation, the relay 161 is activated to permit error-controlled operation of the focus-adjusting motor 129. Otherwise, the motor 129 is grounded by the relay to serve as a dynamic brake and to inhibit further operation of the motor

129. Therefore, the error signal from amplifier 141 attributable to deviation of a work surface from location at the focal plane of the imaging system is applied to the focus-adjusting motor 129 via power amplifier 163 under IN-RANGE conditions when the relay 161 is activated.

The user level offset 139 provides a method for adjusting the trigger level of comparator 165 or the offset voltage on focus-adjusting motor 129. This may be useful for compensating for chromatic errors introduced by the objective lens 16 while passing various frequencies of laser beams 11, 13. This user level offset 139 may also be useful for defocusing the lens to a predetermined level.

With reference now to the graph of Figure 15, there is shown a curve of signal strength of the total sum signal 171 from amplifier 169 as a function of the light detected by detectors operating on both reflected beams. At signal levels below the minimum sum level established by reference source 146, the detector output levels are not IN-RANGE and the circuitry of Figure 13 does not provide reliable focusing operation. However, as the detected light levels increase, because of an increase in sample reflectivity (with the laser 55 operating at maximum output power), the total sum 171 of detector outputs exceeds the minimum sum level 147 which activates the IN-RANGE circuitry, allowing the system to drive motor 129 so that focus is attained. Thereafter, the power output 181 from laser diode 55 may be decreased without loss of auto-focusing capability. Accordingly, the operating power level 181 of laser diode 55 is controlled by the circuitry of Figure 13 to provide optimal power level for enhanced signal to noise ratio without detector or amplifier saturation so that the total sum signal 171 attains a level relative to the desired sum level 172 established by the source 173. The power level of laser diode 55 may thus be reduced by the differential amplifier 175, and power amplifier 179 in approximate proportion to the total sum of detector outputs in order to maintain the total sum 171 of detector outputs substantially constant with light levels on the detectors, as illustrated in Figure 15.

Referring now to Figure 16, step 201 represents the incidence of the laser spot on detector 1. Block 205 represents the signal output from the left side of detector 1 and 207 denotes the detector output on the right side. The difference between the left side output and the right side output is calculated in 213. Similarly, the second detector receives 203 an incidence spot and produces left and right side outputs in 209 and 211 respectively. The difference between the second detector left and right outputs from 209 and 211 produce an output difference in 215. The sum of the first detector left and right outputs are summed in 217, and the sum of the second detector left and right outputs are summed in 219. Step 221 calculates the difference between the first detector difference output and the second detector difference output. Step 229 sums the difference output signal from 221 with a user-adjustable offset level in 223 to produce an error signal. This error signal is amplified 223 sufficiently to control a motor. Step 243 tests the signal polarity. If the error signal is less than zero, the motor moves 247 upwards. If the signal is greater than zero, the motor moves 249 downwards. If the error signal produced from 229 is equal to zero, as shown in 235, then a range signal is generated in 241.

Step 227 adds the sum outputs from 217 and 219 to produce a total sum output. Step 225 represents a minimum detector sum reference level, and this reference level is compared to the total sum output from 227 in 231. If the total sum output from 227 exceeds the minimum detector sum reference level in 225, motor movement is enabled 237, and a signal is generated indicating "in-range". If the total sum does not exceed the minimum detector sum reference level from 225, then the motor movement is inhibited 239. A second reference level is generated 245 to check whether a desired detector sum reference level is achieved. The total sum output from 227 is compared 251 against this desired detector sum reference level from 245. If the total sum from 227 is less than that of the desired detector sum reference level in 245, the laser source is checked 253 to determine if maximum power has already been obtained. If these laser sources are not already operating at

maximum power, the laser power level is increased 259. If the total sum output from 227 is equal to that of the desired detector sum reference level in 245, the power level of the laser source is maintained 255. If the total sum output from 227 exceeds than the desired detector sum reference level in 245, then the output level of the laser source is checked 257 to determine if minimum power has already been attained. If the laser is not already operating at minimum power, the power level of the laser is decreased 261.

Therefore, the auto-focusing system and method according to the present invention provides control signals for operating a focus-adjusting motor coupled to an optical imaging system in a manner that provides wide capture range and dynamic, real-time focus adjustments over a wide variety of conditions of a work surface positioned in the imaging system.

I claim:

1. An apparatus for producing an indication of focussing upon an object to be viewed at the focal plane of an optical system having a defined path along an optical axis through an objective lens, the apparatus comprising:

Source means for producing a pair of measuring beams having defined paths eccentric to said optical axis;

Optical means positioned along the optical axis for transmitting said measuring beams eccentrically through said objective lens in converging relationship onto the object positioned near a focal plane of the optical system;

return reflection means positioned along the optical axis for transmitting reflections of the measuring beams from said object to positions on an image plane that are related to the position of the object relative to the focal plane;

a pair of photodetectors positioned near the image plane for generating electrical signals in response to reflections of the measuring beams supplied thereto, the magnitudes of the electrical signals varying with the positions of the reflections of the measuring beams upon the photodetectors;

circuit means coupled to receive the electrical signals from the pair of photodetectors for producing an output therefrom in proportion to the relative coincidence between the position of the object and the focal plane of the optical system.

2. The apparatus in claim 1 wherein the means for producing two laser beams is a single laser source having beam splitting means for separating the laser source into two discrete beams.

3. The apparatus in claim 2 wherein the beam splitting means is an optical polarizing means.

4. The apparatus in claim 2 wherein the means for producing two laser beams is a pulsed, single laser source which is time multiplexed.

5. The apparatus in claim 1 wherein the laser measuring beams operate in the infrared frequency range.

6. The apparatus in claim 1 wherein the laser measuring beams are produced using two separate laser sources of differing frequencies.

7. The apparatus in claim 1 having additional pairs of photodetectors which may be selectively substituted and combined to vary the range within which said measuring spots may be detected.

8. The apparatus in claim 1 wherein the return reflection means includes an optical element for splitting the reflections of the measuring beams into discrete beam paths.

9. A method for automatically producing an indication of focussing upon an object to be viewed at the focal plane of an optical system having a defined path along an optical axis through an objective lens and having a pair of photodetectors positioned near an image plane of the optical system, the method comprising the steps of:

aligning a pair of measuring beams eccentric to said optical axis;

passing said measuring beams through an objective lens and onto an object;

transmitting the reflections of said measuring beams from the object through the objective lens;

directing each of the reflected measuring beams onto a separate one of the pair of photodetectors to form a spot of illumination at a position thereon indicative of the orientation of the object relative to the focal plane;

measuring the relative positions of the spots of illumination on the photodetectors; and

determining the position of the object relative to the objective focal plane from the relative coincidence between the measured positions of the spots of illumination on the respective photodetectors.

10. An electronic circuit for detecting the magnitude and relative coincidence of a pair of coplanar spots of illumination, the circuit comprising:

a pair of differential photodetectors positioned near the image plane for generating differential electrical signals in response to spots of illumination, the magnitude of the

electrical signals varying with the positions of the spots of illumination about said image plane; and

a difference amplifier circuit with inputs connected to the differential photodetectors and an output which provides an error signal indicating the magnitude and direction of variance between the two sets of differential input signals.

11. The apparatus in claim 10 having an electric motor means connected to the output of said difference amplifier circuit for varying the displacement between said object and said objective focal plane in response to the signal generated by the electronic circuit.

12. The electronic circuit in claim 10 having a comparator means with inputs from said difference amplifier and an adjustable zero offset source, which produces a range trigger signal representing the difference between the differential signals produced by said pair of photodetectors, wherein said range trigger signal indicates when the displacement between said objective focal plane and said object is zero.

13. The apparatus in claim 11 wherein the electronic circuit includes an electronic adjustment means for defocusing the lens to a predetermined level.

14. The apparatus in claim 11 wherein the electronic circuit contains a compensating means for rejecting chromatic errors of said objective as a function of the wavelength or wavelength range of said beams.

15. The electronic circuit in claim 10 including a summing and comparison amplifier circuit with a first set of summing inputs connected to said differential photodetectors, a second input connected to an input offset signal, and an output which indicates the electrical state in which the sum of the signals produced by the photodetectors exceeds the magnitude of the input offset signal.

16. The electronic circuit in claim 15 wherein the output power of said laser source is controlled by said summing and comparison amplifier circuit output signal in order to produce optimum measuring beam illumination.

17. A method for detecting the magnitude and relative coincidence of a pair of coplanar spots of illumination incident on separate differential photodetectors, wherein the method comprises the steps of:

generating differential electrical signals in response to spots of illumination on the differential photodetectors;

sensing said differential signals; and

subtracting one differential signal from the other to produce an output error signal indicating the magnitude and relative coincidence of said spots of illumination.

18. The method in claim 17 further including the step of summing the magnitudes of each of the differential photodetectors in order to indicate the total illumination of the spots on the photodetectors.

19. The method in claim 17 further including the step of comparing the error signal with a user offset signal to provide a level trigger when the spots of illumination are coincident.

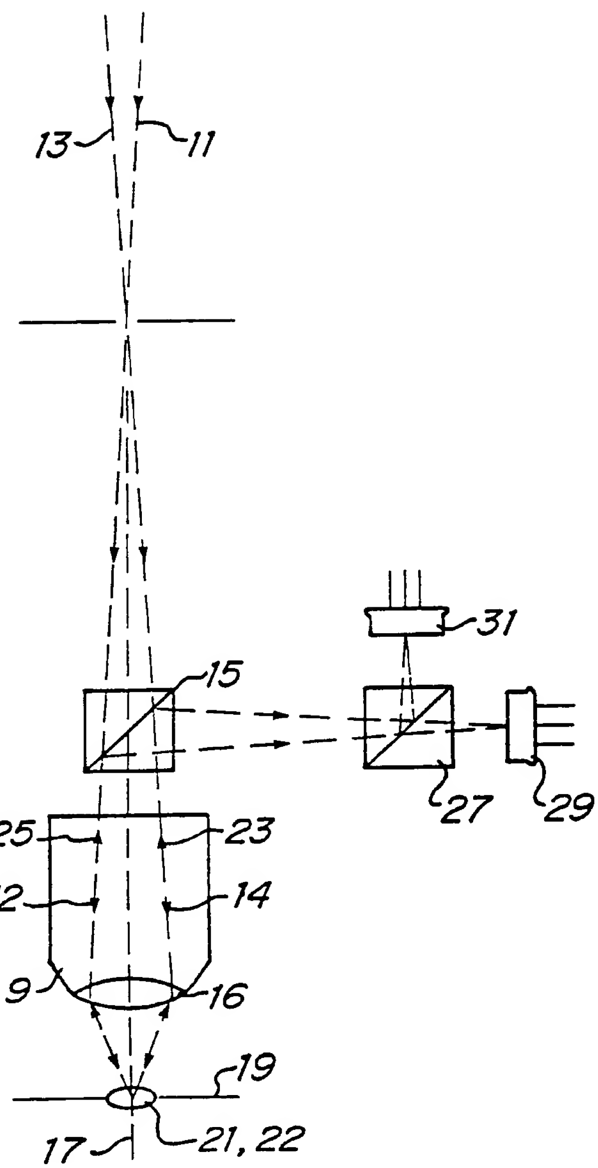
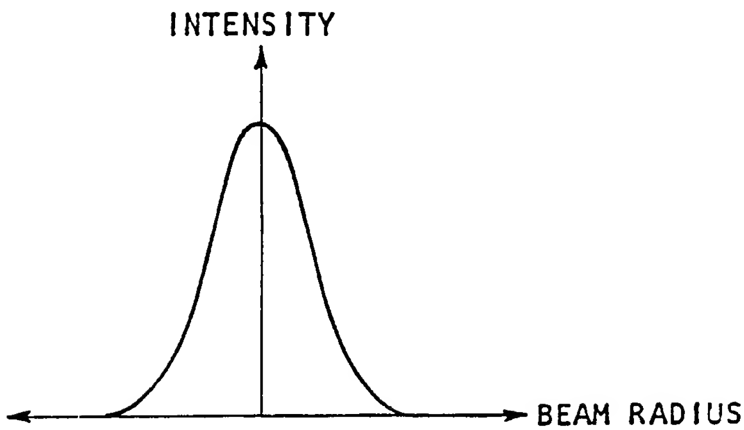


Figure 1



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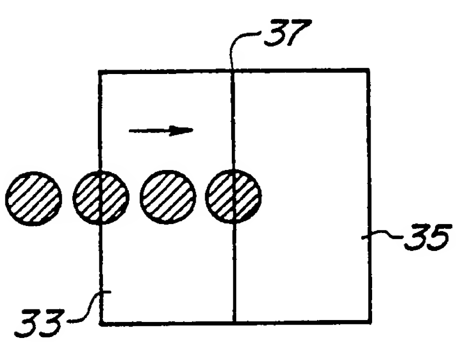

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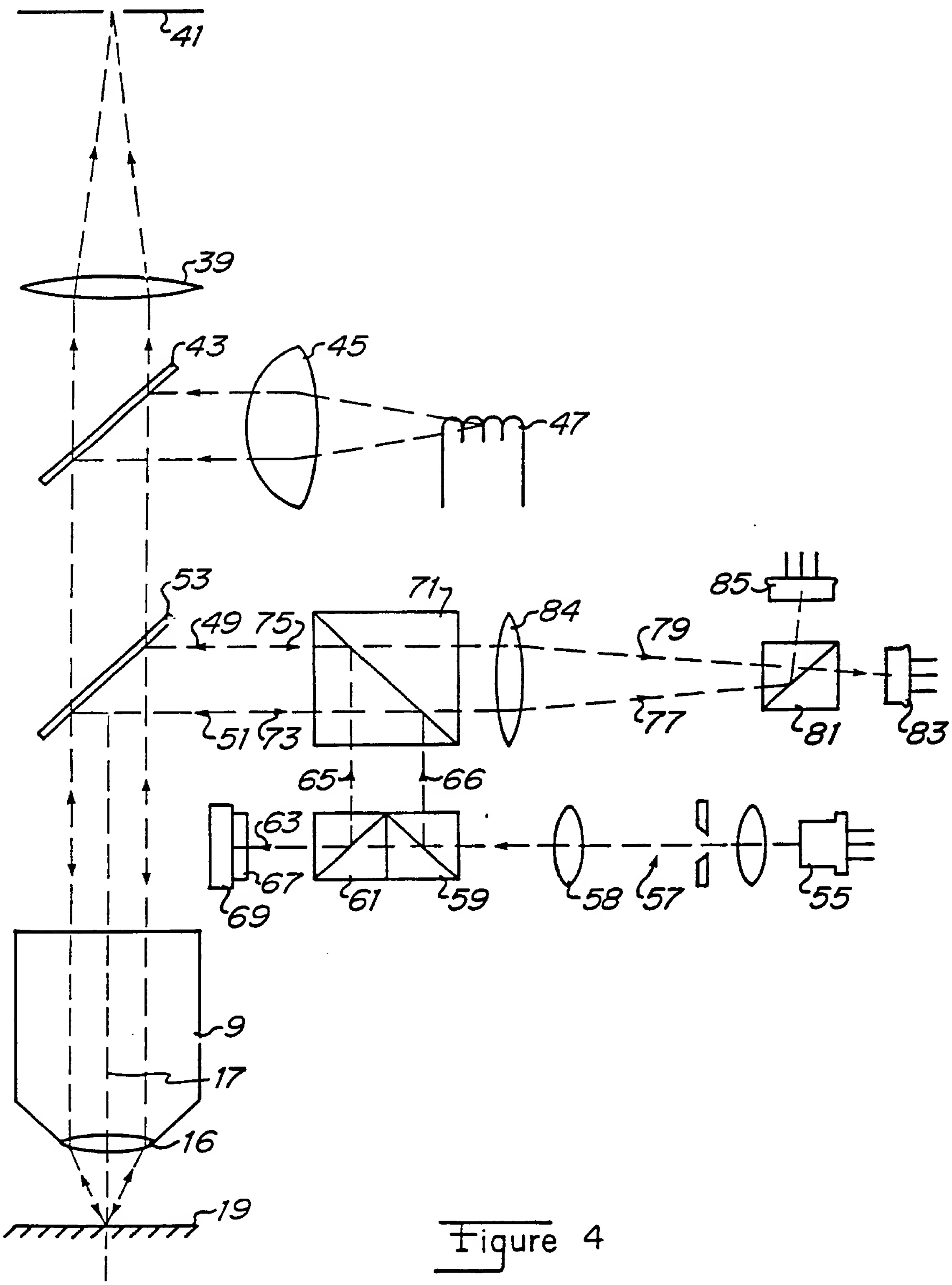
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Figure 4

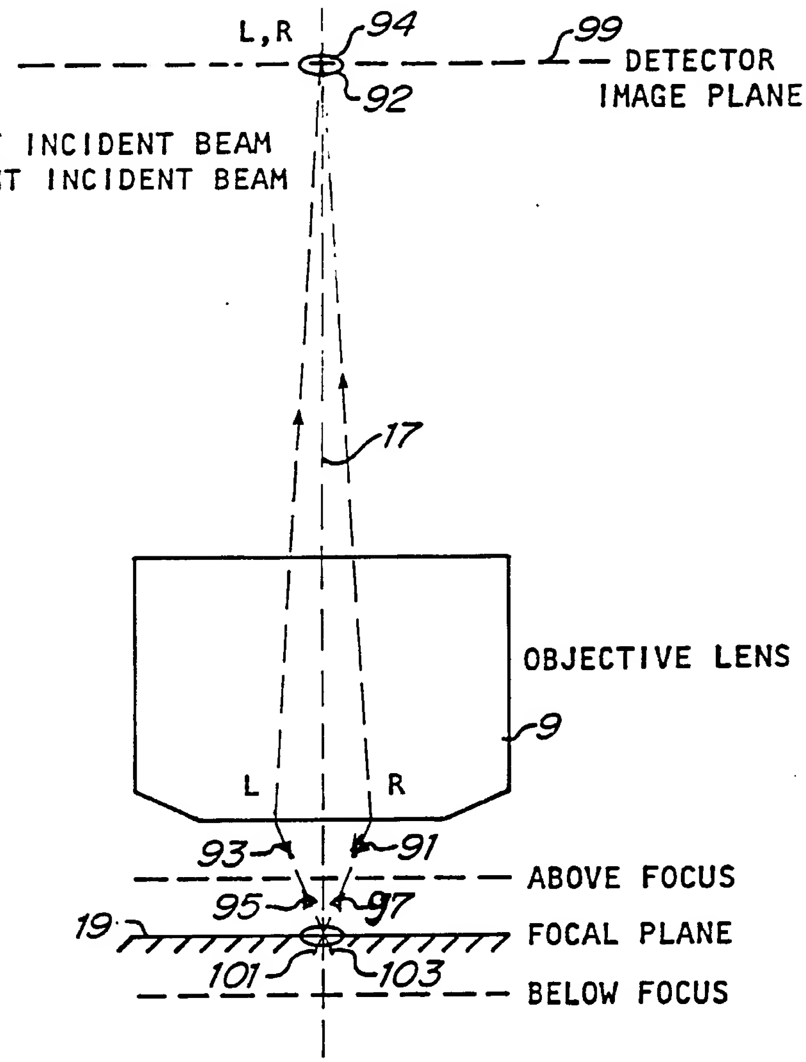
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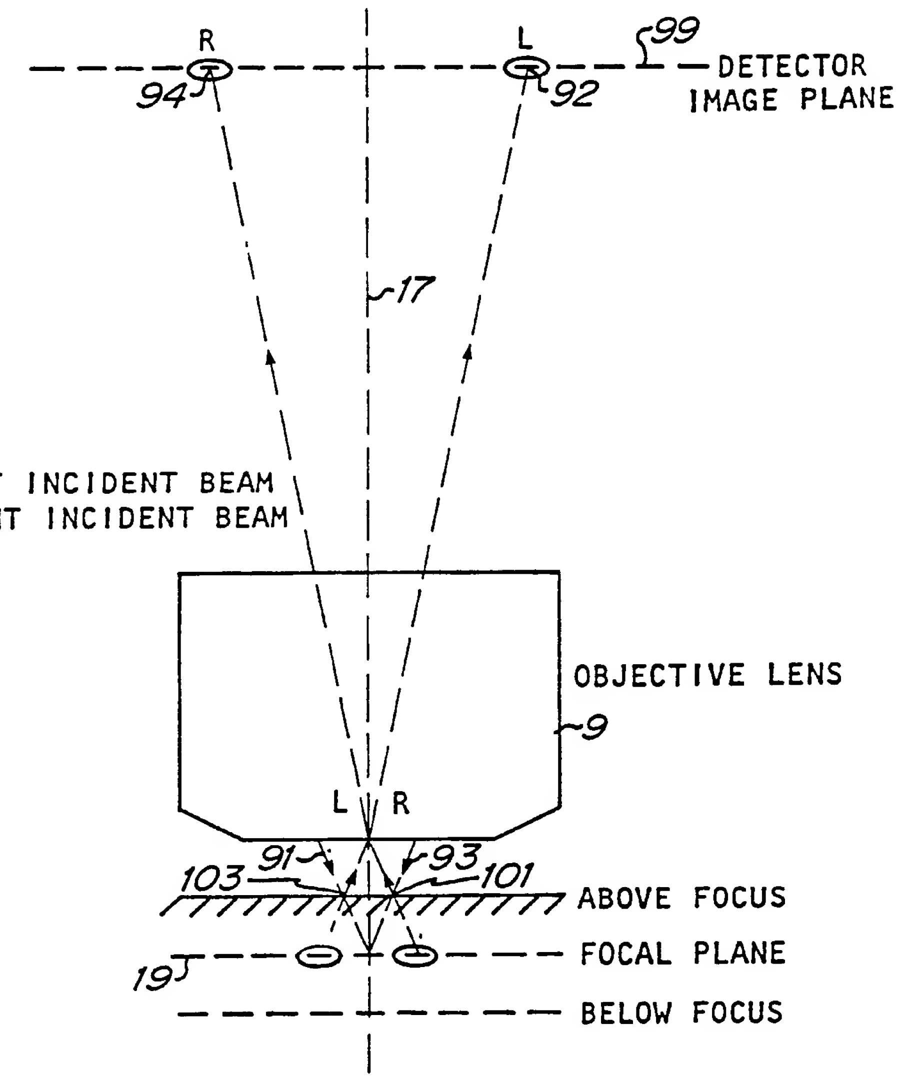
Figure 5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BELOW FOCUS

Figure 6

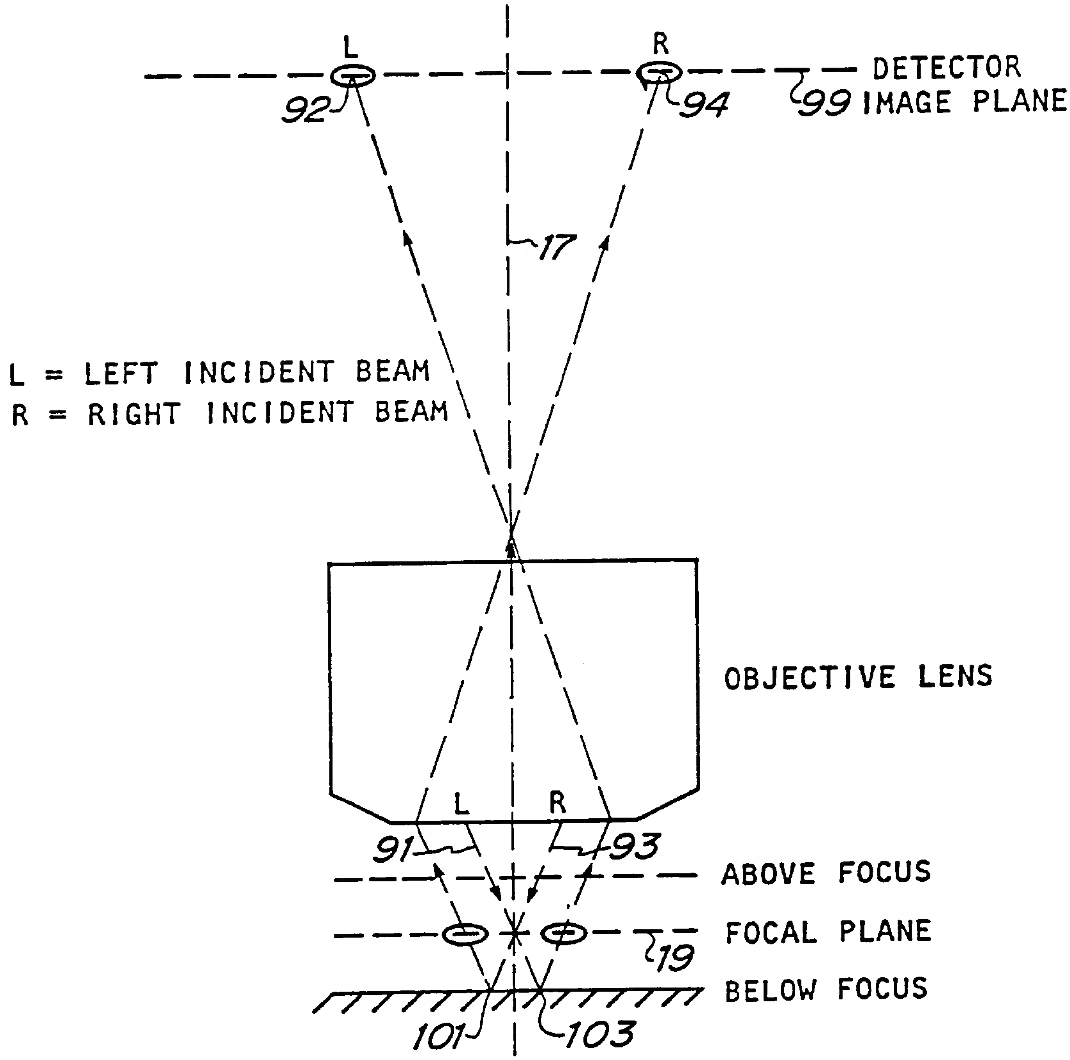
L
R
DETECTOR
IMAGE PLANE
92
94
99
17
L = LEFT INCIDENT BEAM
R = RIGHT INCIDENT BEAM
OBJECTIVE LENS
L
R
91
93
ABOVE FOCUS
FOCAL PLANE
19
BELOW FOCUS
101
103

Figure 7

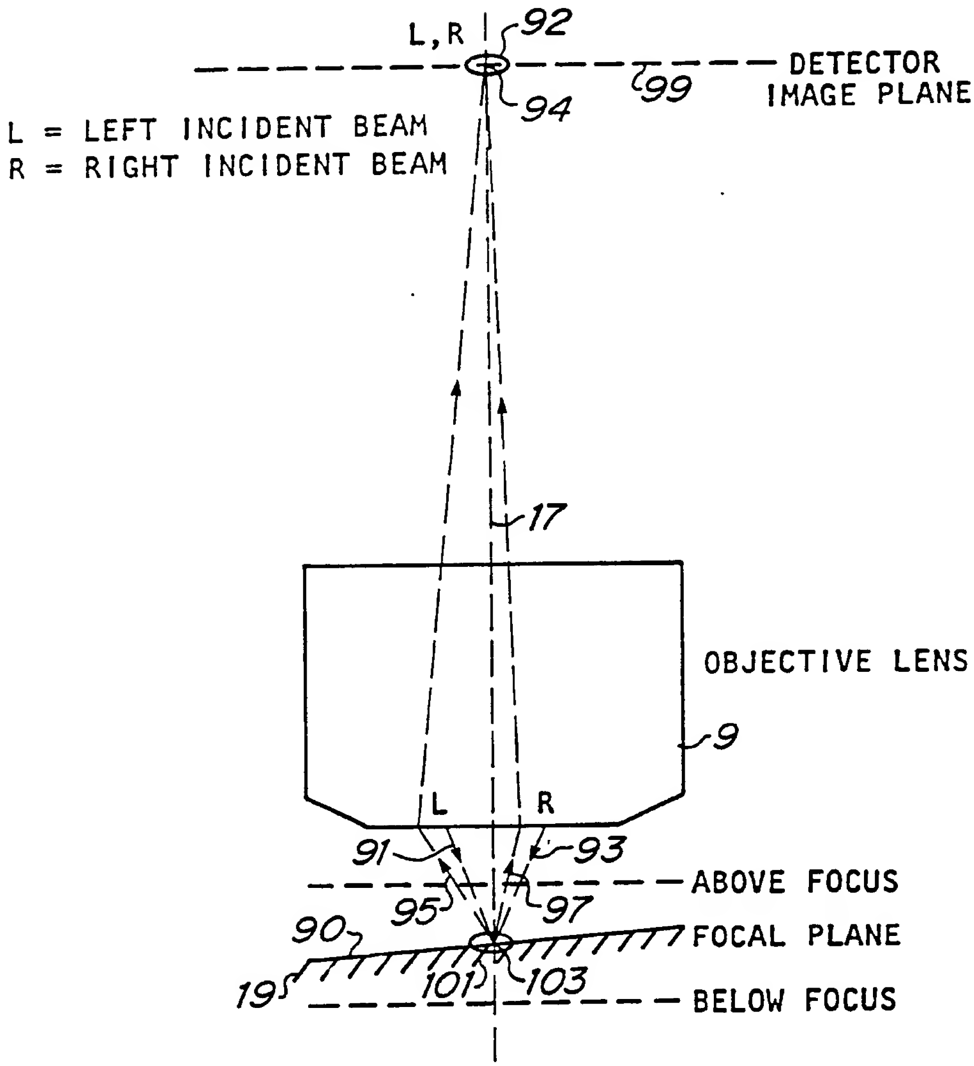
L,R
92
DETECTOR
IMAGE PLANE
99
94
L = LEFT INCIDENT BEAM
R = RIGHT INCIDENT BEAM
17
OBJECTIVE LENS
9
L
R
91
93
ABOVE FOCUS
95
97
90
FOCAL PLANE
19
101
103
BELOW FOCUS

Figure 8

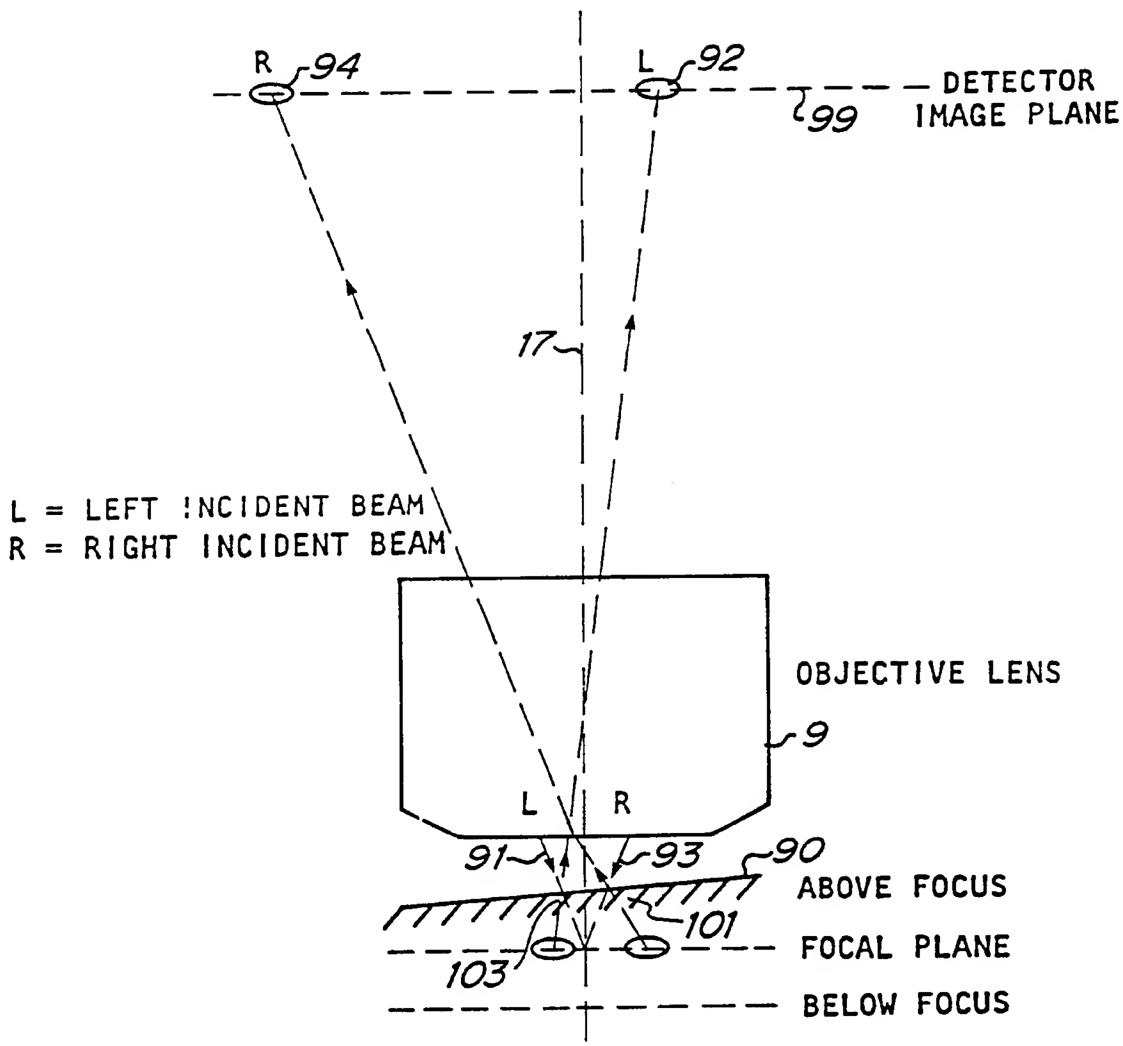
R 94
L 92
DETECTOR IMAGE PLANE
99
17
L = LEFT INCIDENT BEAM
R = RIGHT INCIDENT BEAM
OBJECTIVE LENS
9
L
R
91
93
90
ABOVE FOCUS
101
FOCAL PLANE
103
BELOW FOCUS

Figure 9

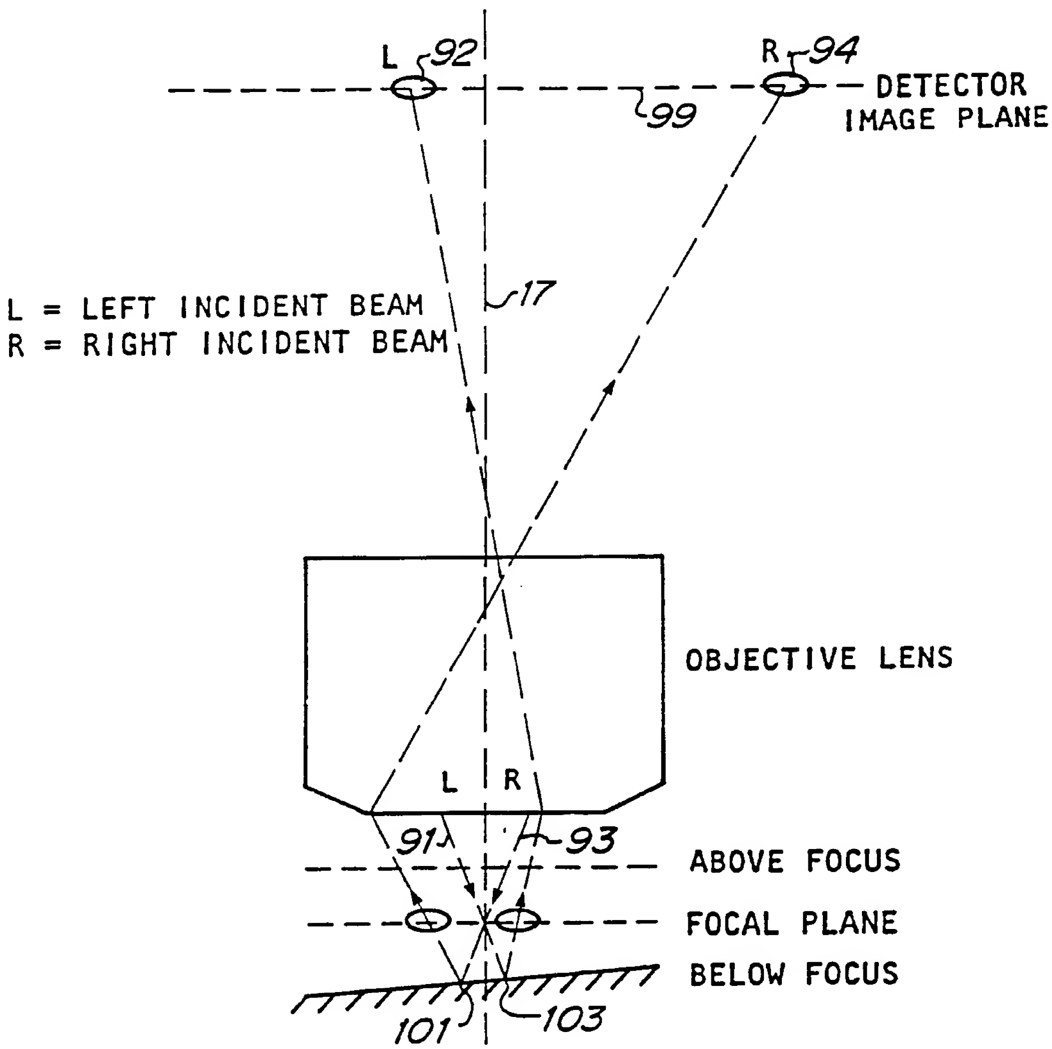
L 92
R 94
DETECTOR IMAGE PLANE
99
17
L = LEFT INCIDENT BEAM
R = RIGHT INCIDENT BEAM
OBJECTIVE LENS
L
R
91
93
ABOVE FOCUS
FOCAL PLANE
BELOW FOCUS
101
103

Figure 10

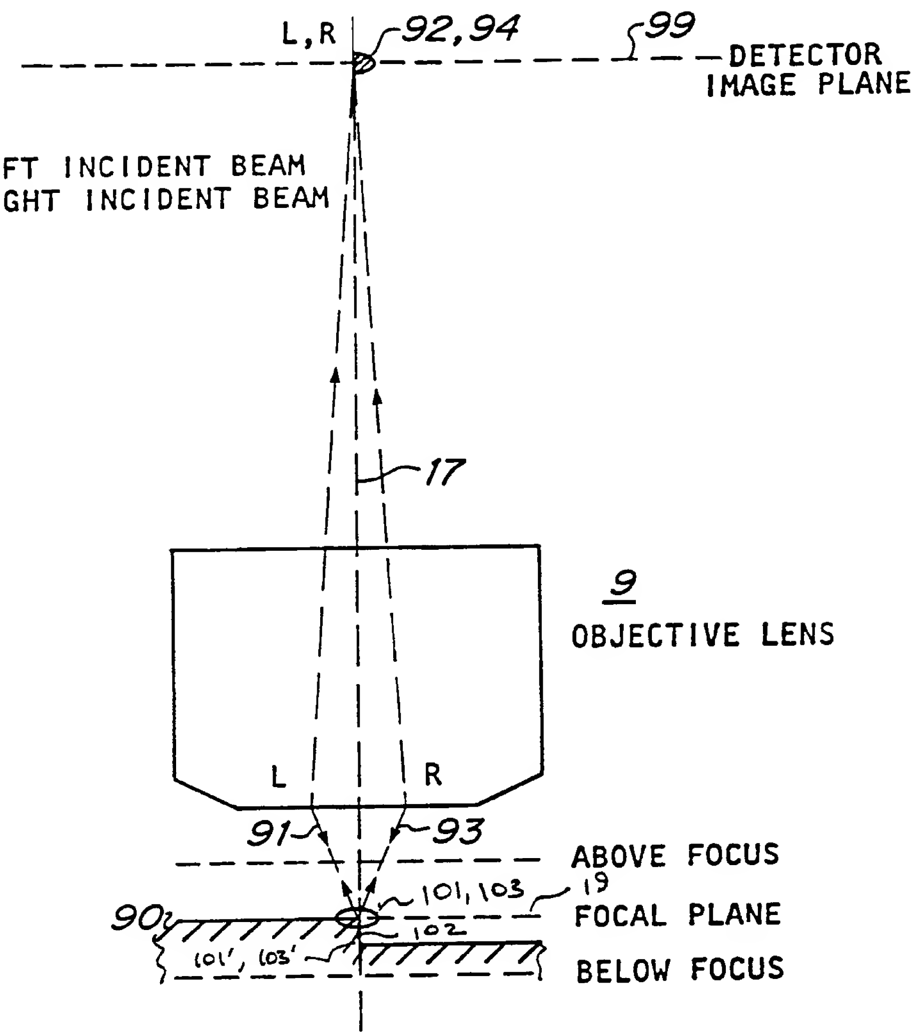
L,R
92,94
99
DETECTOR
IMAGE PLANE
L = LEFT INCIDENT BEAM
R = RIGHT INCIDENT BEAM
17
9
OBJECTIVE LENS
L
R
91
93
ABOVE FOCUS
101, 103
19
90
FOCAL PLANE
102
101', 103'
BELOW FOCUS

Figure 11

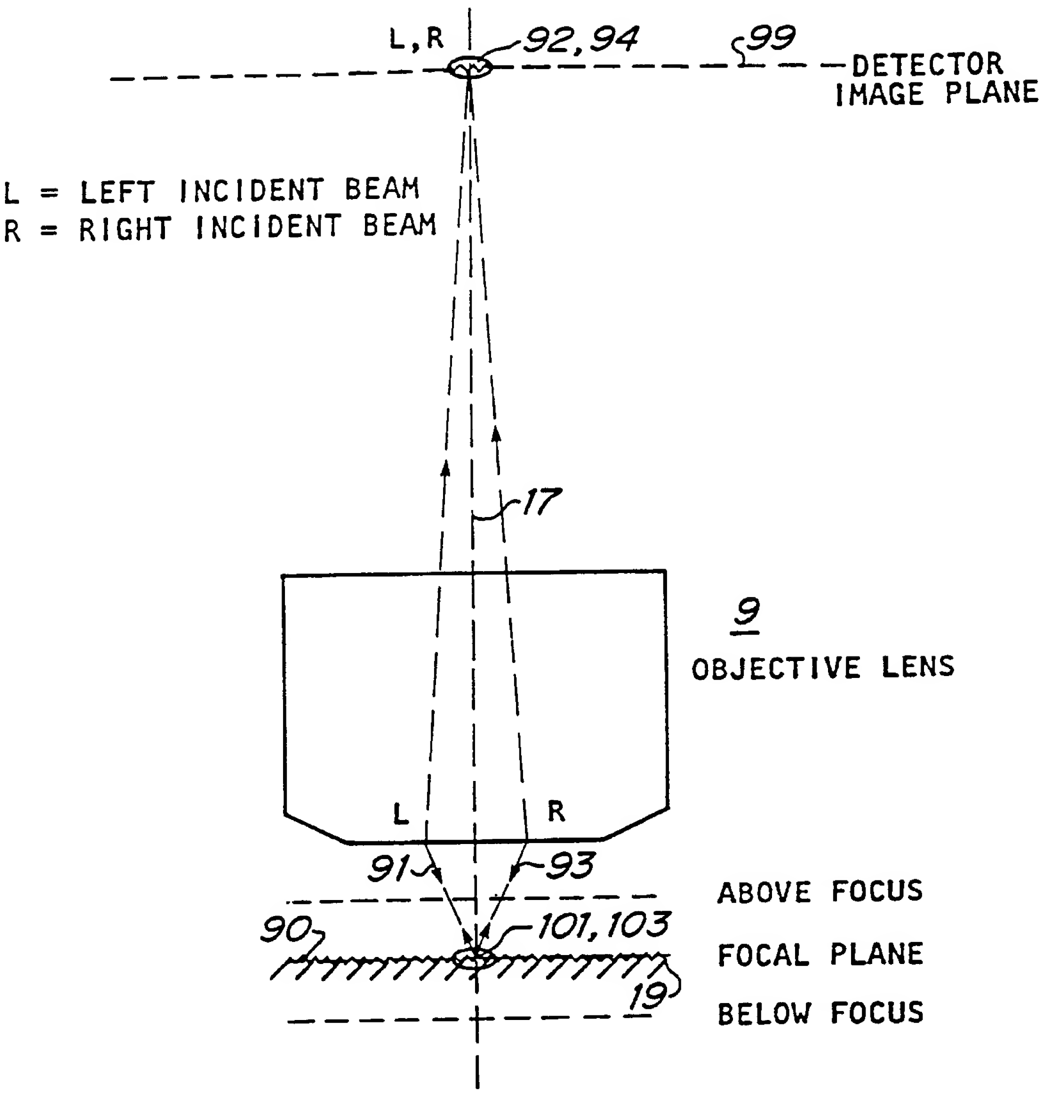
L,R
92,94
99
DETECTOR IMAGE PLANE
L = LEFT INCIDENT BEAM
R = RIGHT INCIDENT BEAM
17
9
OBJECTIVE LENS
L
R
91
93
ABOVE FOCUS
90
101,103
FOCAL PLANE
19
BELOW FOCUS

Figure 12

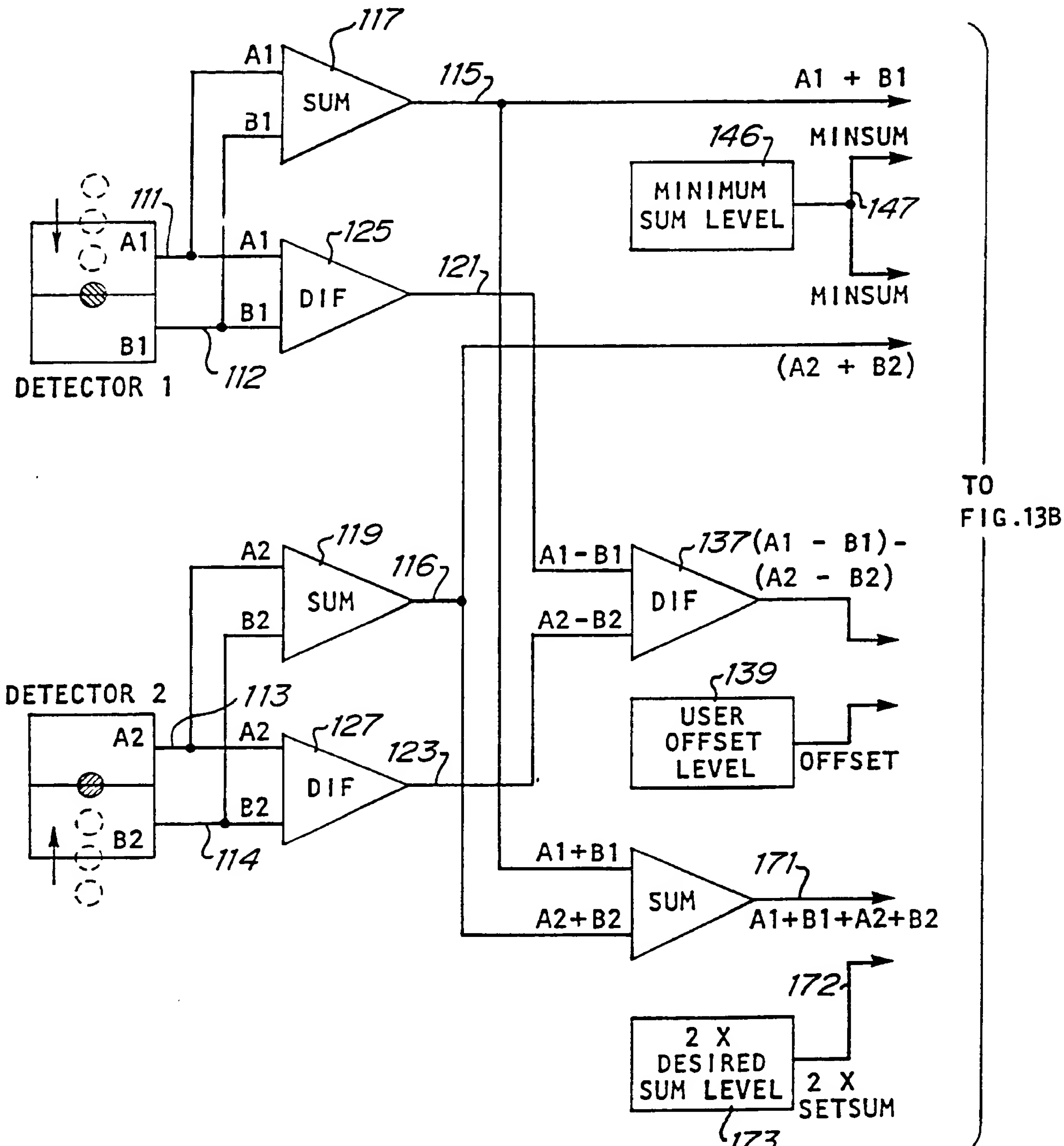
A1
B1
SUM
117
115
A1 + B1
146
MINSUM
MINIMUM
SUM LEVEL
147
MINSUM
111
A1
B1
A1
B1
DIF
125
121
(A2 + B2)
112
DETECTOR 1
TO
FIG.13B
A2
B2
SUM
119
116
A1-B1
A2-B2
DIF
137
(A1 - B1)-
(A2 - B2)
DETECTOR 2
113
A2
B2
A2
B2
DIF
127
123
114
139
USER
OFFSET
LEVEL
OFFSET
A1+B1
A2+B2
SUM
171
A1+B1+A2+B2
172
2 X
DESIRED
SUM LEVEL
173
2 X
SETSUM

Figure 13A

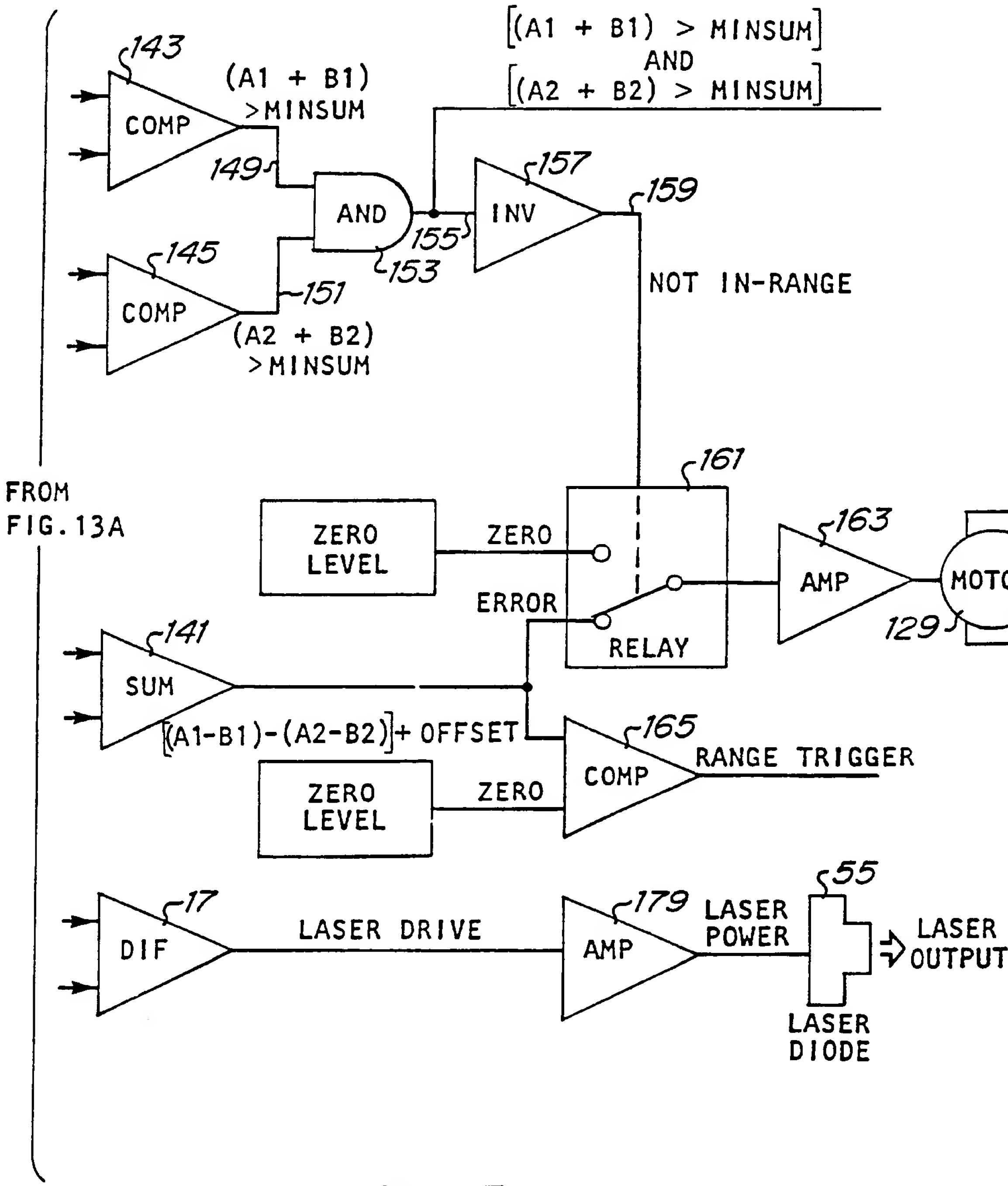
143
COMP
(A1 + B1)
>MINSUM
149
145
COMP
151
(A2 + B2)
>MINSUM
AND
153
155
[(A1 + B1) > MINSUM]
AND
[(A2 + B2) > MINSUM]
157
INV
159
NOT IN-RANGE
FROM
FIG.13A
161
ZERO
LEVEL
ZERO
ERROR
RELAY
163
AMP
MOTOR
129
141
SUM
[(A1-B1)-(A2-B2)]+ OFFSET
165
COMP
RANGE TRIGGER
ZERO
LEVEL
ZERO
17
DIF
LASER DRIVE
179
AMP
LASER
POWER
55
LASER
OUTPUT
LASER
DIODE

Figure 13B

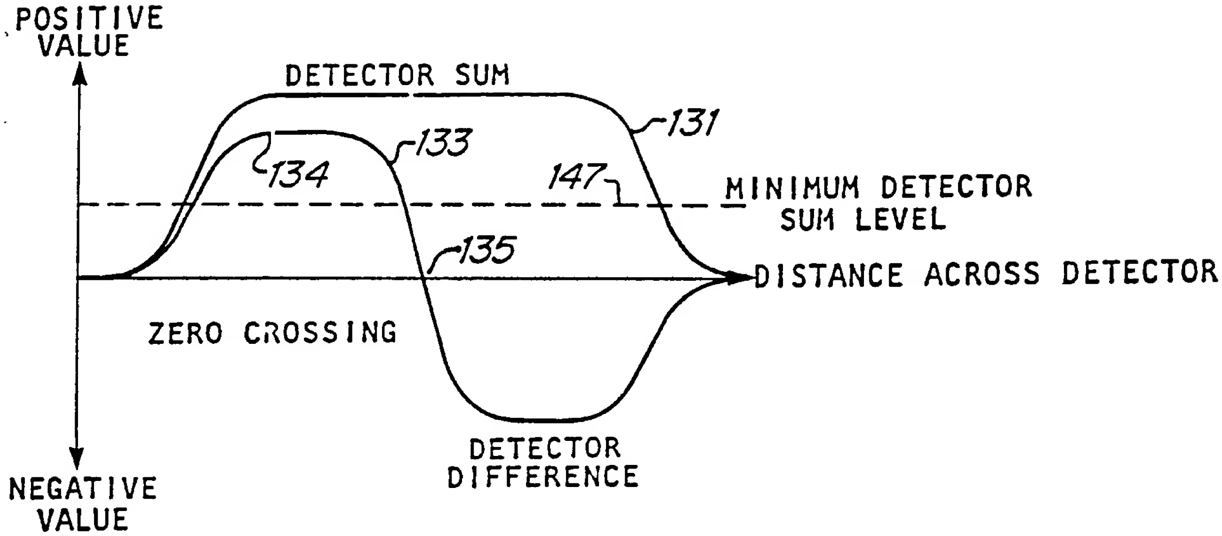

Figure 14

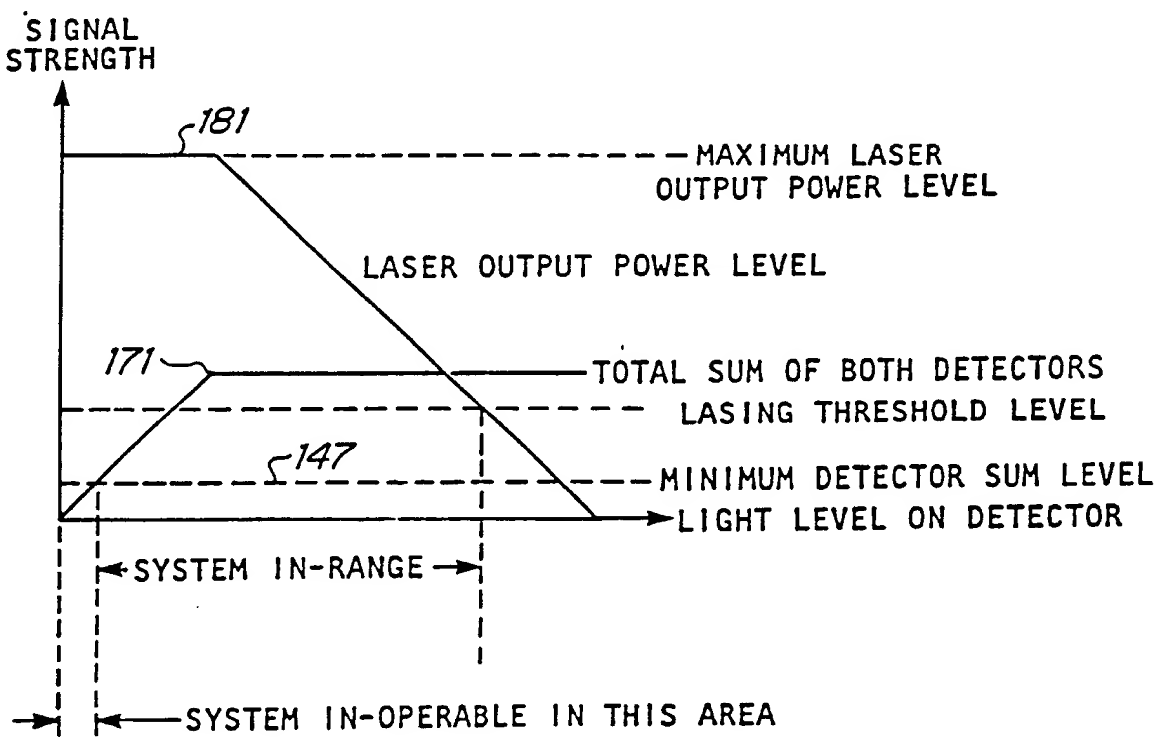

Figure 15

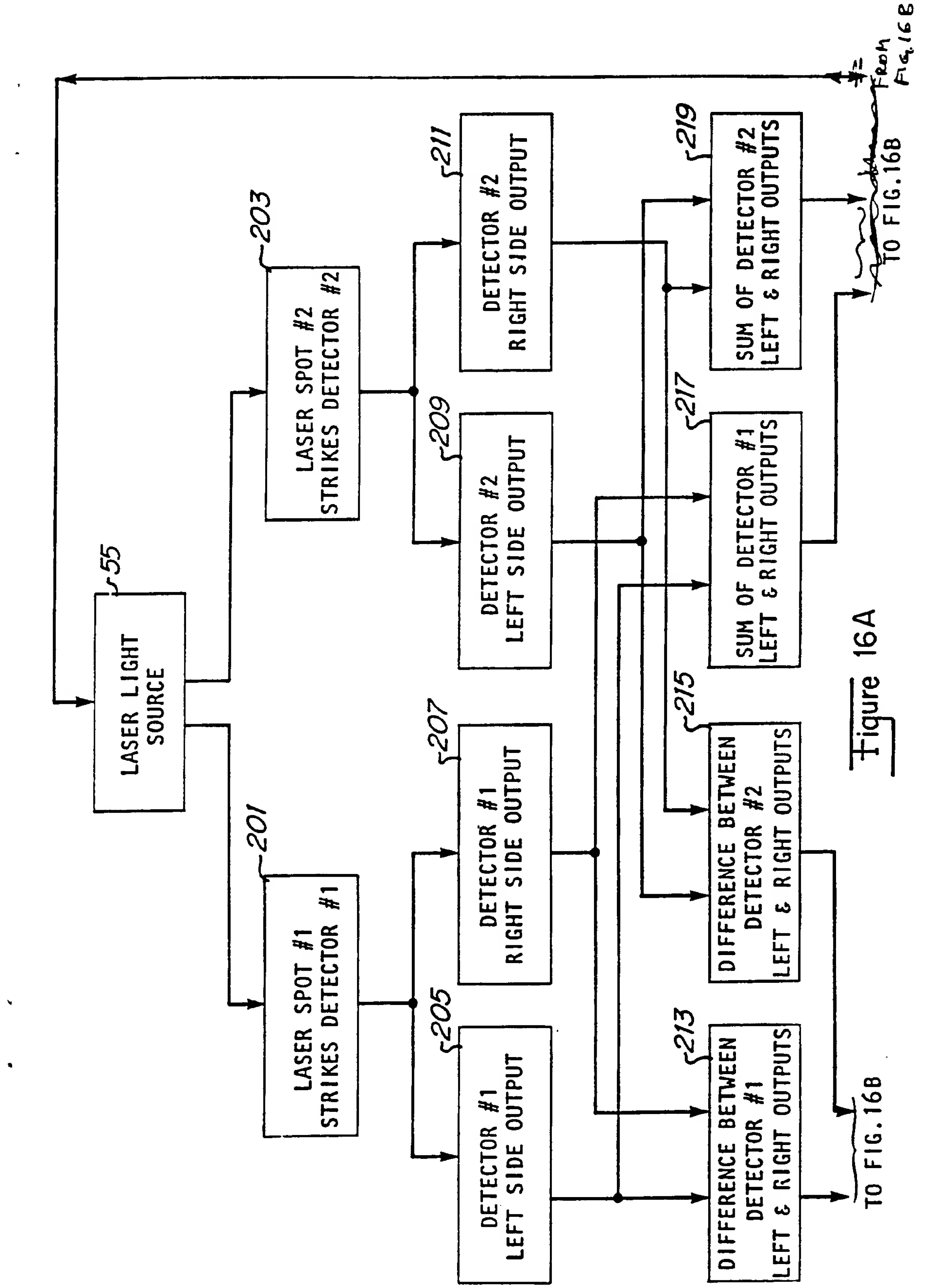
LASER LIGHT SOURCE
55
LASER SPOT #2 STRIKES DETECTOR #2
203
LASER SPOT #1 STRIKES DETECTOR #1
201
DETECTOR #2 RIGHT SIDE OUTPUT
211
DETECTOR #2 LEFT SIDE OUTPUT
209
DETECTOR #1 RIGHT SIDE OUTPUT
207
DETECTOR #1 LEFT SIDE OUTPUT
205
SUM OF DETECTOR #2 LEFT & RIGHT OUTPUTS
219
SUM OF DETECTOR #1 LEFT & RIGHT OUTPUTS
217
DIFFERENCE BETWEEN DETECTOR #2 LEFT & RIGHT OUTPUTS
215
DIFFERENCE BETWEEN DETECTOR #1 LEFT & RIGHT OUTPUTS
213
TO FIG.16B
TO FIG.16B
TO FIG.16B
FROM FIG.16B

Figure 16A

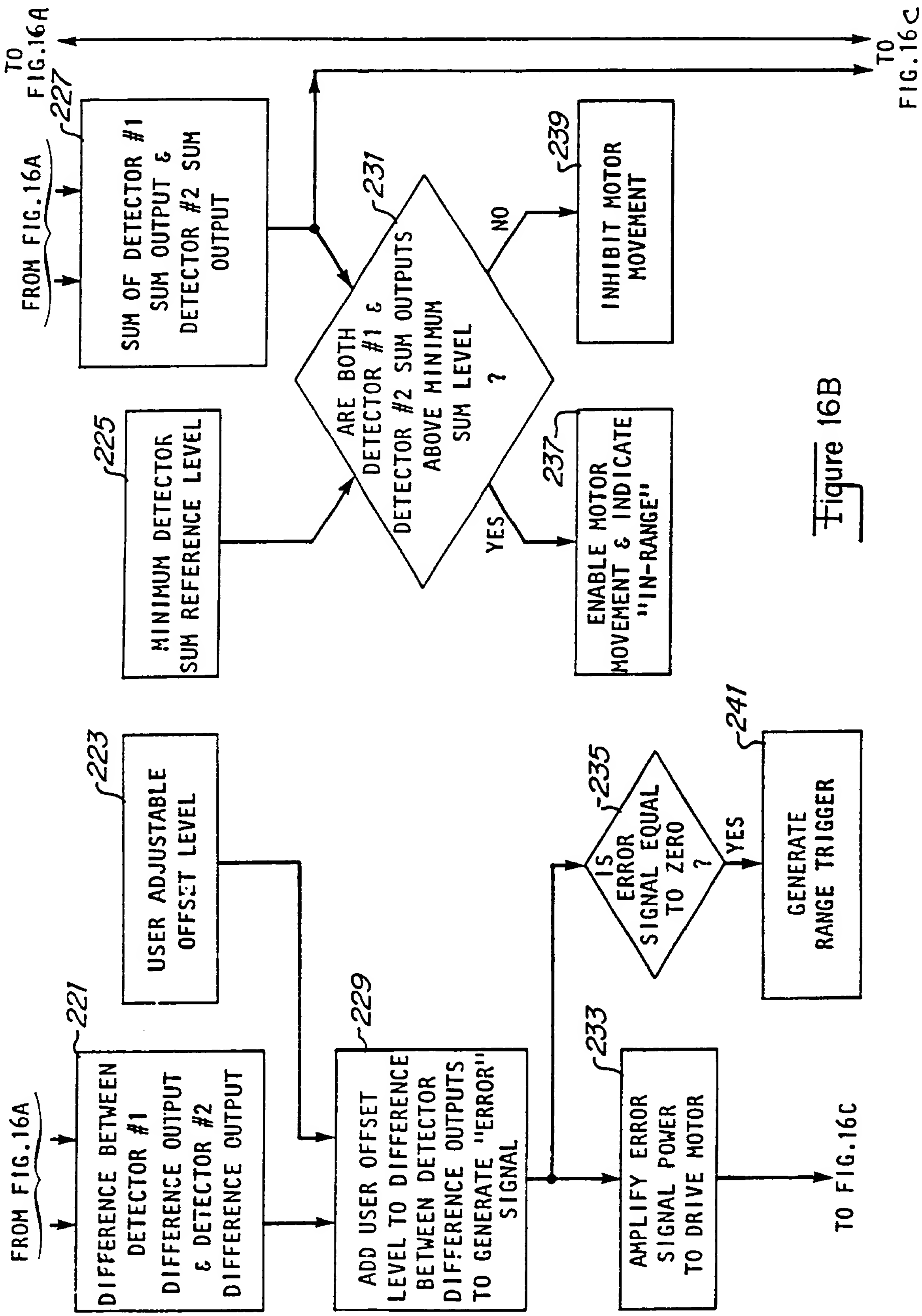
FROM FIG.16A
SUM OF DETECTOR #1 SUM OUTPUT & DETECTOR #2 SUM OUTPUT
227
TO FIG.16A
TO FIG.16C
TO FIG.16C
MINIMUM DETECTOR SUM REFERENCE LEVEL
225
ARE BOTH DETECTOR #1 & DETECTOR #2 SUM OUTPUTS ABOVE MINIMUM SUM LEVEL ?
231
NO
YES
INHIBIT MOTOR MOVEMENT
239
ENABLE MOTOR MOVEMENT & INDICATE "IN-RANGE"
237
FROM FIG.16A
DIFFERENCE BETWEEN DETECTOR #1 DIFFERENCE OUTPUT & DETECTOR #2 DIFFERENCE OUTPUT
221
USER ADJUSTABLE OFFSET LEVEL
223
ADD USER OFFSET LEVEL TO DIFFERENCE BETWEEN DETECTOR DIFFERENCE OUTPUTS TO GENERATE "ERROR" SIGNAL
229
IS ERROR SIGNAL EQUAL TO ZERO ?
235
YES
GENERATE RANGE TRIGGER
241
AMPLIFY ERROR SIGNAL POWER TO DRIVE MOTOR
233
TO FIG.16C

Figure 16B

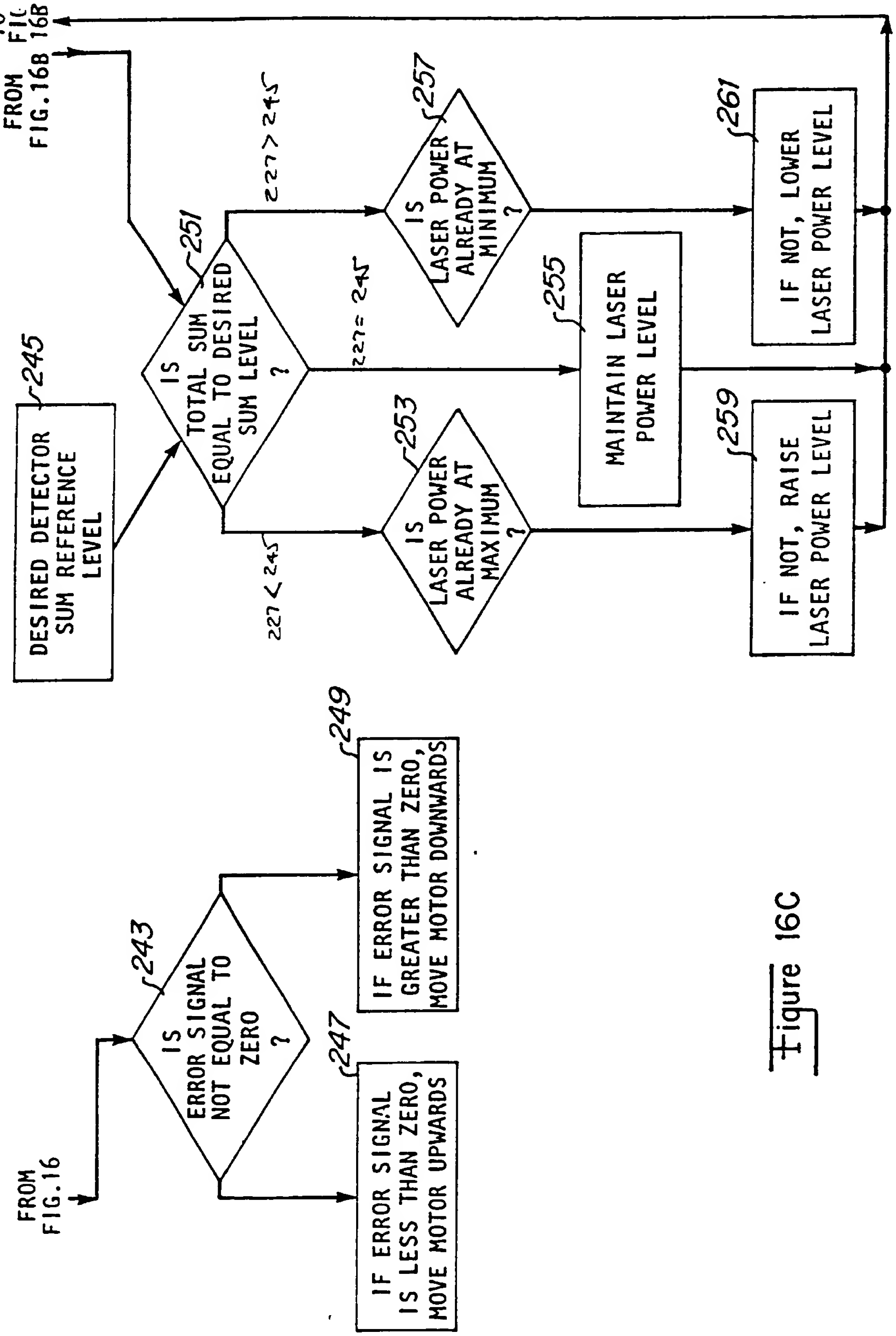
FROM FIG.16B
TO FIG 16B
DESIRED DETECTOR SUM REFERENCE LEVEL
245
IS TOTAL SUM EQUAL TO DESIRED SUM LEVEL ?
251
227 > 245
227 = 245
227 < 245
IS LASER POWER ALREADY AT MINIMUM ?
257
MAINTAIN LASER POWER LEVEL
255
IS LASER POWER ALREADY AT MAXIMUM ?
253
IF NOT, LOWER LASER POWER LEVEL
261
IF NOT, RAISE LASER POWER LEVEL
259
FROM FIG.16
IS ERROR SIGNAL NOT EQUAL TO ZERO ?
243
IF ERROR SIGNAL IS GREATER THAN ZERO, MOVE MOTOR DOWNWARDS
249
IF ERROR SIGNAL IS LESS THAN ZERO, MOVE MOTOR UPWARDS
247

Figure 16C

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/07344

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [6]

According to International Patent Classification (IPC) or to both National Classification and IPC
IPC(5): G01J 1/20, H01J 40/14
US CL : 250/201.4, 250/206.1

II. FIELDS SEARCHED

Minimum Documentation Searched [7]

Classification System	Classification Symbols
U.S.	205/201.1, 201.2, 201.3, 201.4, 206.1, 213VT, 561 354/402,403 356/1,4,141,152

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [9]

Category *	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No. [13]
A	US,A 3,718,821 (VISCHULIS) 27 February 1973	10-19
A	US,A 3,838,275 (STAUFFER) 24 September 1974	10-19
A	US,A 3,836,772 (STAUFFER) 17 September 1974	10-19
A	US,A 4,374,324 (VAN ROSMALEN ET AL) 15 February 1983	1-9
A	US,A 4,577,095 (WATENABE) 18 March 1986	10-19
A	US,A 4,705,941 (YAMADA ET AL) 10 November 1987	1-9
A	US,A 4,721,850 (SAKAI ET AL) 26 January 1988	1-9
A	US,A 4,725,722 (MAEDA ET AL) 16 February 1988	1-9
A	US,A 4,855,585 (NONAKA) 08 August 1989	10-19
A	US,A 4,931,630 (COHEN ET AL) 05 June 1990	1-9

* Special categories of cited documents: [10]
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
04 March 1992	12 MAR 1992
International Searching Authority	**Signature of Authorized Officer**
ISA/US	Stephone B. Allen

International Application No. PCT/US91/07344

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [1]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers , because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers.........., because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

3. ☐ Claim numbers____________, because they are dependent claims not drafted in accordance with the second and third sentences of PCT Rule 6.4(a).

VI. ☒ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [2]

This International Searching Authority found multiple inventions in this international application as follows:

See Attachment

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.
2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:
3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:
4. ☐ As all searchable claims could be searched without effort justifying an additional fee, the International Searching Authority did not invite payment of any additional fee.

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.